

Effects of a Grass-Selective Herbicide in a Vetch–Rye Cover Crop System on Corn Grain Yield and Soil Moisture

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ABSTRACT

Cover crop spring kill date and species affect spring water use by covers, summer moisture conservation by cover crop residue, and yield of subsequent corn (*Zea mays* L.). Data are needed on spring management strategies for cover crop mixtures of hairy vetch (HV) (*Vicia villosa* Roth) and cereal rye (*Secale cereale* L.), compared to pure stands, to make accurate corn fertilizer nitrogen (FN) recommendations and to optimize moisture use vs. conservation by cover crop mixtures. A 2-yr study evaluated a grass-selective herbicide (GSH) applied in late March to a pure rye cover and a vetch–rye mixture, allowing the vetch to accumulate N until early May. These treatments were compared to early May-killed pure rye, pure vetch, vetch–rye mixture, and no-cover control. Corn FN rates of 0, 45, 90, 180, and 270 kg ha⁻¹ were applied in June. Corn grain yield was greater following pure stands of vetch than following any other cover crop treatment, regardless of kill date. The average economic optimum FN rate was about 150 kg N ha⁻¹ without a cover. With a cover crop and compared to the control, the hairy vetch replaced about 80 kg FN ha⁻¹, the vetch–rye mixture replaced about 15 kg FN ha⁻¹, while the pure rye removed an additional 50 kg FN ha⁻¹. Spring soil moisture (0–20 cm) beneath growing covers was greater than or equal to the no-cover controls throughout the spring and the summer. There was no significant difference in corn FN response for the early kill date of rye with a GSH, compared with the conventional late-kill date.

COVER CROPS can provide benefits or liabilities to corn production systems. These benefits or liabilities include effects on corn grain yield, soil moisture, and conservation of N that might otherwise be lost from the agricultural system (Meisinger et al., 1991). For example, HV or cereal rye cover crops use soil moisture in the early spring through transpiration, but can conserve moisture after they are killed by providing a surface mulch to reduce evaporation and improve infiltration (Clark et al., 1997; Corak et al., 1991; Ebelhar et al., 1984; Munawar et al., 1990). The precise effects of cover crops on soil moisture are complex and depend on factors such as: amount and intensity of rainfall, soil infiltration rate, soil surface crusting, slope, etc. These interacting factors result in variable effects of cover crops on spring soil–water depletion vs. summer soil–water conservation from site-to-site and year-to-year. Vaughan

and Evanylo (1998) concluded that cover crop moisture conservation was a secondary factor affecting corn yield in Virginia, while cover crop water conservation was a major contributor to improved corn yield in Maryland (Clark et al., 1997).

The effects of cover crop species on corn grain yield have been more consistent across locations and years than soil moisture effects. Hairy vetch has been shown to regularly supply large amounts of N (50–155 kg ha⁻¹) to a succeeding corn crop (Ebelhar et al., 1984; Holderbaum et al., 1990a; Hargrove, 1986; Clark et al., 1995; Ranells and Waggoner, 1996; Seo et al., 2000), while rye generally requires 10 to 50 kg N ha⁻¹ of additional FN (Mitchell and Teel, 1977; McCracken et al., 1989; Waggoner, 1989; Munawar et al., 1990; Eckert, 1988; Vyn et al., 2000). Corn yield with no additional FN following vetch–rye mixtures (Clark et al., 1994; Vaughan and Evanylo, 1998), or legume–wheat (*Triticum aestivum* L.) mixtures (Holderbaum et al., 1990a) were less than after pure vetch, but greater than yield following pure rye or no-cover crop.

The timing of spring cover crop kill can affect spring water use by the growing cover crop, the amount of cover crop residue left after killing, surface mulching benefits, and N accumulation with subsequent effects on the FN response of corn. Some researchers have suggested an early kill of vetch (Corak et al., 1991; Ebelhar et al., 1984) or of cereal rye (Munawar et al., 1990; Raimbault and Vyn, 1991) to prevent soil moisture depletion. In different site–years rye has been shown to dry the soil too much (Decker et al., 1994), or to keep the soil too wet (Eckert, 1988). Advantages of late-killed rye (Gallaher, 1977; Moschler et al., 1967; Mitchell and Teel, 1977; Sullivan et al., 1991; Clark et al., 1997) or vetch (Clark et al., 1995, 1997; Corak et al., 1991; Decker et al., 1994; Duiker and Curran, 2005) are often associated with surface mulching benefits. Vetch–rye mixtures have the potential to combine some of the advantages of both cover crops.

Limited data are available on the effects of spring management of grass–legume mixtures, compared to pure stands, on subsequent corn yield and soil moisture. These data are needed to optimize kill date of pure-stand or mixed-stand covers, and to more accurately assess corn FN needs. Our general objective was to evaluate cover-crop management practices that were aimed at reducing excessive spring growth of rye, yet allowing

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Abbreviations: CKL, no-cover check; DM, dry matter; FN, fertilizer N; GSH, grass selective herbicide; HV, hairy vetch; LSD, least significant difference; MXL, late-killed vetch–rye mixed cover; MXP, early killed rye in vetch–rye mixed cover; RCB, randomized complete block; RYL, late-killed pure rye cover; RYP, early killed pure rye cover; VTL, late-killed vetch cover.

high vetch production. The specific objectives were to evaluate management strategies of: an early (late March) application of a GSH to a vetch-rye mixture or a pure rye cover, compared to a late-kill (early May) of all vegetation in a vetch-rye mixture, pure rye, pure vetch, and no-cover control. The effects of these treatments were evaluated by documenting corn grain yield response to four rates of FN and by monitoring surface-soil moisture. Cover crop yield, cover crop N content, and corn N uptake are presented in a companion paper (Clark et al., 2007).

MATERIALS AND METHODS

This 2-yr study (1989–1991) was conducted on a Mattapex silt loam soil (fine-silty, mixed, mesic, typic Hapludult) on the Atlantic Coastal Plain near Quantico, MD. Cover crop treatments were no-cover, hairy vetch, cereal rye, and a vetch-rye mixture. The details of the experiment such as: seeding rates, plot size, planting and harvesting dates, tillage practices, herbicide program, etc., are presented in a companion paper (Clark et al., 2007). Briefly, the experimental design was a split-plot randomized complete block replicated four times. Whole-plot treatments were six cover crop and spring kill-date combinations: no-cover check (CKL), early killed rye (RYP), late-killed rye (RYL), early killed rye in vetch-rye mixture (MXP), late-killed of vetch-rye mixture (MXL), and late-killed vetch (VTL). The early kill treatments received a GSH in late March applied to the rye and vetch-rye mixture and the late-kill treatments received a herbicide application in early May to kill all cover crop vegetation. Subplots were given variable rates of corn FN: 0, 45, 90, and 180 kg N ha⁻¹ for vetch; and 0, 90, 180, and 270 kg N ha⁻¹ for the other cover crop treatments, applied as ammonium nitrate broadcast by hand on 22 May 1990 and 31 May 1991, when corn was at the two- to three-leaf stage. The major factor of interest in this study was the application of a GSH in late March to the vetch-rye mixture, to control the growth of rye and encourage vetch growth.

Gravimetric soil samples were taken with 1.9 cm diam. cores to 20 cm beginning at the early kill date (20 or 21 March), and at approximately weekly intervals thereafter until late August. Gravimetric soil samples were weighed fresh, dried for 24 h at 105°C and then reweighed. Soil moisture data were taken only on treatments that did not receive FN in 1990. Soil moisture data from 1990 showed greater soil moisture depletion due to greater corn growth after pure vetch and high FN treatments. Therefore, high FN treatments were also sampled for soil moisture changes in 1991.

Corn grain yield was measured 20 Sept. 1990 and 17 Sept. 1991 by hand-harvesting 3.7 m of the two center rows, subsampling whole plants and ears for testing, and drying for 72 to 96 h at 60°C for moisture determination. All grain data are adjusted to a 15.5% moisture basis.

Data were analyzed using SAS (SAS Institute, 1988). Corn data were analyzed as a split-plot, and gravimetric soil moisture data were analyzed as a split-plot for each individual date and as a split-split plot in time when analyzed across sample dates. For the combined analysis over years, year was considered a fixed effect (McIntosh, 1983). Corn response data were fitted to a quadratic-plus-plateau model (Cerrato and Blackmer, 1990). Economic rates of FN (the FN rate at which marginal returns from increased yield equaled the marginal cost of FN) were calculated using a corn price of \$98.20 Mg⁻¹, and FN cost of \$0.55 kg⁻¹ (\$2.50 bu⁻¹, \$0.25 lb⁻¹ FN).

RESULTS AND DISCUSSION

Rainfall Distribution

Rainfall amount and frequency are well-known factors affecting corn grain yield in nonirrigated agriculture, particularly rainfall during the period of pollination. Detailed rainfall data are presented in Fig. 1 of the companion paper (Clark et al., 2007), but a summary is given here as it influenced corn grain yield. Total rainfall was adequate for good corn yield in both years of this study, as demonstrated by the yield plateaus of 9

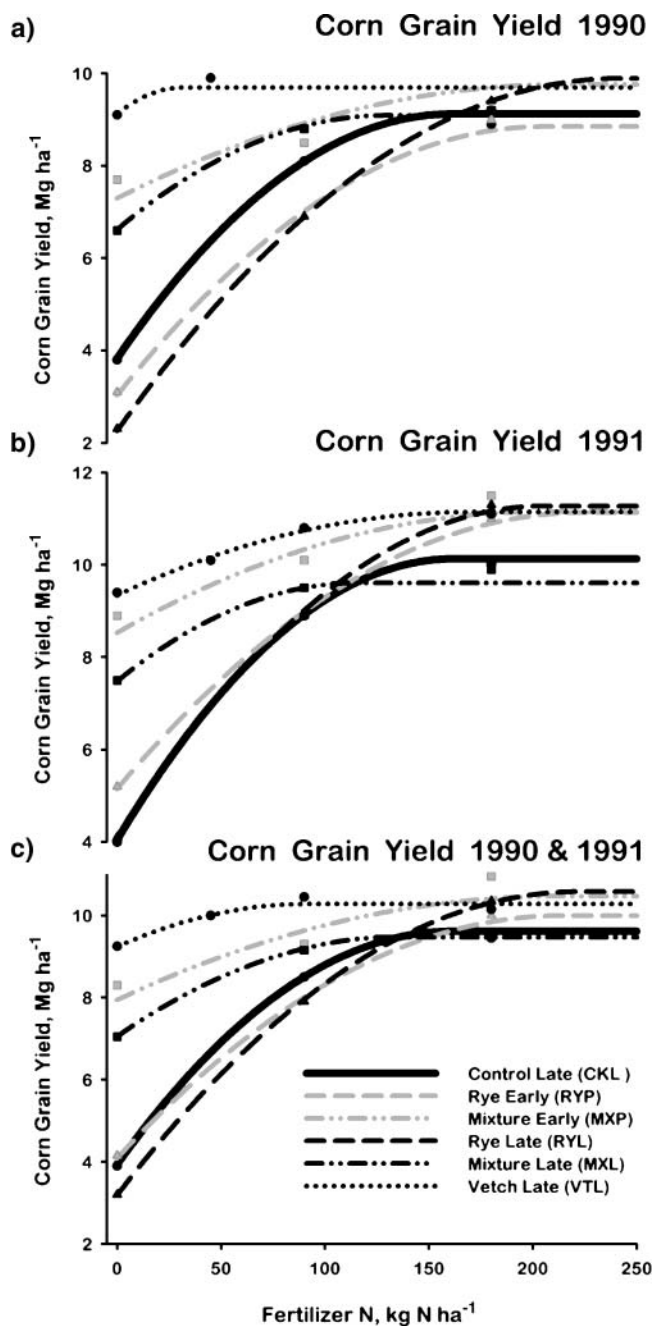


Fig. 1. Corn grain yield (Mg ha⁻¹) in (a) 1990, (b) 1991, and (c) 1990–1991 average after cover crop and kill-date treatments of: rye killed early (RYP) or late (RYL), vetch killed late (VTL), vetch-rye mixture killed early (MXP) or late (MXL), or no-cover (CKL).

and 11 Mg ha⁻¹ for 1990 and 1991, respectively (Fig. 1 and Table 1). However, the 2 yr had somewhat different rainfall distribution within the growing season. In 1990, April and May were above average but June and July were below normal. This resulted in some July moisture stress during corn tasseling that lowered yield potential. In 1991 the April, May, and June rainfall was below normal, but July rainfall was above-normal resulting in good pollination and higher yield potentials.

The rainfall patterns are also important for interpreting the soil moisture data. Above-average March rainfall in 1990 and 1991 influenced soil moisture during early April, when cover crop growth was greatest. The March and April rainfall is especially important in cover crop systems because cover crop water use may deplete soil moisture to the detriment of the subsequent corn crop. Cover crop water-use efficiency has been reported to range from 20 mm Mg⁻¹ dry matter (DM) (Allison et al., 1998) to 40 mm Mg⁻¹ DM (Rogasik et al., 1992). The rainfall in May through August is also of interest because of the potential water conservation benefit provided by cover crop residue. Specific effects of rainfall on soil moisture are noted and discussed below.

Corn Grain Yield

Statistical analysis revealed significant effects of whole plot (cover crop species) and subplot (FN rate) treatments on corn yield in both years. Year effects were also significant but interactions of treatments with year were not significant. The significant year effect was due to better rainfall distributions in 1991, which resulted in a 1 to 2 Mg ha⁻¹ yield increase compared to 1990.

Grain yield for 1990 (Fig. 1a) with no FN applied was greatest following vetch, least after rye, and intermediate following the vetch-rye mixture. Other researchers

(Holderbaum et al., 1990a, Clark et al., 1994, 1997; Vaughan and Evanylo, 1998; Ranells and Waggoner, 1997) have also reported similar findings with yield after pure legumes being greater than legume-grass mixtures, followed by yield after grass cover crops. Yield following vetch with no FN was as great, or greater than, all other treatments regardless of FN rate. Grain yield responses to FN were obtained with applications up to 180 kg ha⁻¹ for the rye treatments, while mixtures did not respond to more than 90 kg N ha⁻¹ and corn after vetch did not significantly respond to FN at all in 1990.

In 1991, more favorable summer rainfall improved corn production and resulted in a stronger response to FN (Fig. 1b). The yield from the unfertilized plots followed the pattern from 1990, i.e., vetch had the greatest yield, mixtures intermediate, and rye or control treatments the lowest. Grain yield after vetch did not significantly respond to more than 45 kg N ha⁻¹, while the corresponding nonresponsive FN levels for vetch-rye mixtures were 90 kg N ha⁻¹, and 180 kg N ha⁻¹ for rye cover crop treatments.

Averaged over years (Fig. 1c), cover crop by FN rate relationships were the same as for individual years, with the no-cover control and the rye treatments giving strong yield responses to FN, the mixtures giving modest responses, and vetch giving the smallest response. There was no significant difference between early vs. late-kill of vetch-rye mixtures or early vs. late-kill of the rye, which indicates that the corn yield was not significantly influenced by the early season application of the GSH.

Nitrogen Response Functions and Economics

Corn grain yield response to FN was fitted to a quadratic-plus-plateau model for individual years and 2-yr averages (Table 1). Cover crop systems have been shown to affect corn growth by: (i) changing the maximum yield of the system, i.e., the plateau yield where N is not limiting (Decker et al., 1994; Clark et al., 1994, 1997) and/or; (ii) changing the shape (with the same limiting yield) of the FN response curve by substituting cover crop N for FN. The quadratic-plateau regression equations contain the combined effects of possible limiting yield differences and FN response differences among the cover crop species and kill-date treatments. Of course, the farmer is faced with the combined effects of cover crops on corn yield when estimating optimum FN rate. Table 1 lists the quadratic-plateau maximum yield values, the FN rate at the beginning of the plateau, and the economic optimum FN rate. The regression analysis showed that the rye covers required higher FN rates than the controls; the lowest FN needs were after vetch, and the mixtures gave intermediate FN optimums. These economic optimum differences did not result from significantly different yield plateaus (Table 1 and Fig. 1c), but rather from the differing shapes of the FN response curves. For example, the vetch response curve shows a small response to FN, while the control and rye FN response curves show a strong N response that is characteristic of a severe N limitation. The greatest differ-

Table 1. Principal reference points for the corn grain yield quadratic-plus-plateau model fit to each cover crop and kill-date treatment, for each year of the study and averaged over years.

Cover crop treatment			Year	Plateau description		Economic optimum FN rate
Crop species	Kill date	Treatment code†		Corn yield	FN rate	
				Mg ha ⁻¹	—kg N ha ⁻¹ —	
No-cover	late	CKL	1990	9.1	161	147
			1991	10.1	162	150
			1990–1991	9.6	162	149
Vetch-rye	early	MXP	1990	9.7	216	163
			1991	11.2	205	161
			1990–1991	10.5	212	162
Vetch-rye	late	MXL	1990	9.1	130	111
			1991	9.6	116	98
			1990–1991	9.4	124	106
Rye	early	RYP	1990	8.9	205	184
			1991	11.1	225	201
			1990–1991	10.0	214	192
Rye	late	RYL	1990	10.0	241	220
			1991	11.3	205	189
			1990–1991	10.5	222	203
Vetch	late	VTL	1990	9.7	32	27
			1991	11.1	170	125
			1990–1991	10.3	92	69

† MXP is vetch-rye mixture killed late March, MXL is vetch-rye mixture killed early May, VTL is vetch killed early May, RYP is rye killed late March, and RYL is rye killed early May.

ences between years can be seen in the nonfertilized yield (Fig. 1a vs. Fig. 1b) and the plateau yield for each cover crop treatment (Table 1).

Using average yield over years, the economic optimum FN rates (in kg N ha⁻¹) were: 149 for the no-cover control, 192 for rye killed early, 203 for rye killed late, 162 for the mixture killed early, 106 for the mixture killed late, and 69 for vetch killed late (Table 1). Hairy vetch therefore replaced about 80 kg FN ha⁻¹ and the late-killed mixture replaced about 45 kg FN ha⁻¹, while the early kill mixture required an extra 15 kg FN ha⁻¹ and the rye plots required an average of 50 kg as additional FN ha⁻¹ compared to the control. Economic analyses of corn grain yield following cover crops of vetch, wheat, or no-cover also produced similar rankings and concluded that vetch provided the highest net revenues and lowest profit-maximizing N rates, while the opposite was observed after the wheat cover (Hanson et al., 1993; Roberts et al., 1998). Other research in Ontario measured corn grain yield response after several cover crops and concluded that a legume cover of red clover (*Trifolium pratense* L.) substantially increased available N to corn, but that rye did not increase available N compared to a no-cover control (Vyn et al., 2000).

The application of the GSH to the vetch-rye mixture or the pure rye cover resulted in neither a large, nor a consistent, difference in the economic optimum FN rates compared to their nontreated counterparts. Therefore, these data show that a GSH application would probably not be economically feasible. However, producers also have less costly approaches that still follow the principle of controlling the growth of rye in the late spring while encouraging vetch growth. One approach would be to harvest the vetch-rye mixture for an early silage crop and allow the vetch to regrow 2 to 3 wk before killing and planting corn. This would prevent the rye from maturing and would produce silage that could be fed or sold. This approach was discussed by Holderbaum et al. (1990b) who reported greater total silage production (cover crop plus corn silage) when crimson clover was harvested as silage, compared to leaving it as a mulch, without additional FN applied. Another alternative would be to mechanically clip the cover crop mixture once the rye reached the boot stage, effectively halting most rye growth while allowing the vetch to regrow and fix additional N.

Soil Moisture

Surface soil moisture measurements are “point in time” measures of soil water that reflect the net effect between rainfall additions and water losses to drainage, evaporation, runoff (likely to be minimal on the nearly level soil of the site), and crop water use. The systematic collection of soil water data over a growing season can provide comparisons of seasonal water status among the cover cropping treatments. Surface soil water contents in the spring and early summer are particularly informative because they can influence corn germination and they represent the zone of greatest root activity during the summer.

In 1990, surface soil moisture was measured gravimetrically on zero FN treatments throughout the spring and summer; data are presented for the period of cover crop growth from the late March GSH application until about 4 wk after corn planting (Fig. 2). Without a seeded cover crop (CKL), soil moisture was equal to or lower than soil moisture under all the cover crops from late March until early June, probably due to greater surface evaporation during the spring season because rainfall was above normal. On 25 April, soil moisture was significantly higher where pure rye had been killed early (RYP) due to higher crop transpiration on the other cover crop plots. The period between late April and mid-May is important for corn germination and development because soil moisture depletion by actively growing covers can result in poor corn growth, as shown by the spring drought in 1986 (Decker et al., 1994). Stipesevic and Kladvko (2005) reported similar moisture conservation benefits from cover crops compared to no-cover, concluding that the additional moisture improved early season corn growth. They also reported that early killed cover crops resulted in greater corn growth in drought conditions due to conservation of soil water (Stipesevic and Kladvko, 2005). By early June 1990, with corn at the five-leaf stage, soil moisture was significantly higher under all cover crop residue than where no cover crop was grown, likely due to lower surface evaporation. These results are consistent with earlier reports (e.g., Clark et al., 1997) of moisture conservation from cover crops.

Soil moisture was also sampled throughout the summer in 1990 on zero FN plots (data not shown), but the data were confounded by differential soil moisture use by corn because unfertilized corn following vetch or vetch-rye mixtures yielded twice as much as corn following rye or fallow (see Fig. 1). To focus on residue effects on soil moisture, soil moisture was also measured on the highest FN plots on 3 Aug. and 15 Aug. 1990 (Table 2). On 3 August soil moisture was higher for the late-killed mixture and rye, suggesting better mulching by the heavier residue cover. Lowest soil moisture was

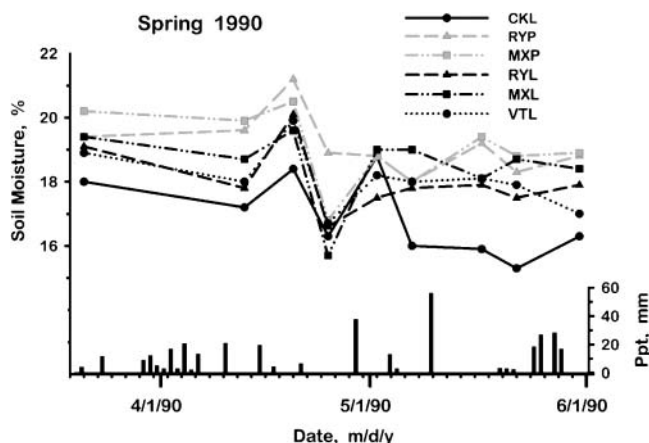


Fig. 2. Surface (0–20 cm) soil moisture contents (g water/100 g soil, i.e., %) during the spring of 1990 under cover crop and kill-date treatments of: rye killed early (RYP) or late (RYL), vetch killed late (VTL), vetch-rye mixture killed early (MXP) or late (MXL), or no-cover (CKL).

Table 2. Surface (0–20 cm) soil moisture contents (g water/100 g soil) under cover crop residue receiving high FN treatments (180 kg N ha⁻¹ for VTL, 270 kg N ha⁻¹ for all others) on two dates in 1990.

Cover crop treatment			Date	
Crop species	Kill date	Treatment code†	3 Aug.	15 Aug.
g water/100 g soil				
No cover	late	CKL	8.0	11.0
Vetch-rye	early	MXP	6.0	13.1
Vetch-rye	late	MXL	8.8	14.9
Rye	early	RYP	7.0	12.0
Rye	late	RYL	9.5	14.8
Vetch	late	VTL	7.5	13.1
Statistics LSD (0.05)			1.0	1.5

† MXP is vetch-rye mixture killed late March, MXL is vetch-rye mixture killed early May, VTL is vetch killed early May, RYP is rye killed late March, and RYL is rye killed early May.

measured for vetch and early killed mixture or rye on that date. Data from 15 August show the same trends after 122 mm of rain and illustrate the greater water conservation with heavier mulches from cover crops.

Soil moisture for 1991 cover crop treatments (Fig. 3) show moisture depletion through mid-April for most cover crop treatments, although the early kill rye plots (RYP) had the highest moisture content. Soil moisture was again lower for the no-cover treatments throughout the spring. By mid-June, all cover crop treatments had more available soil moisture than the no-cover control, which continued to be lower for much of the summer. The 1991 summer gravimetric data for the highest FN plots (Fig. 4) indicate little significant difference in a year of ample summer rainfall and high water use by corn. However, the late-killed rye (RYL) or vetch-rye (MXL) resulted in better moisture conservation throughout the summer, for example from mid-June to late August.

Soil moisture data from both years indicate that actively growing cover crops did not deplete spring soil moisture, but in fact conserved more soil moisture than

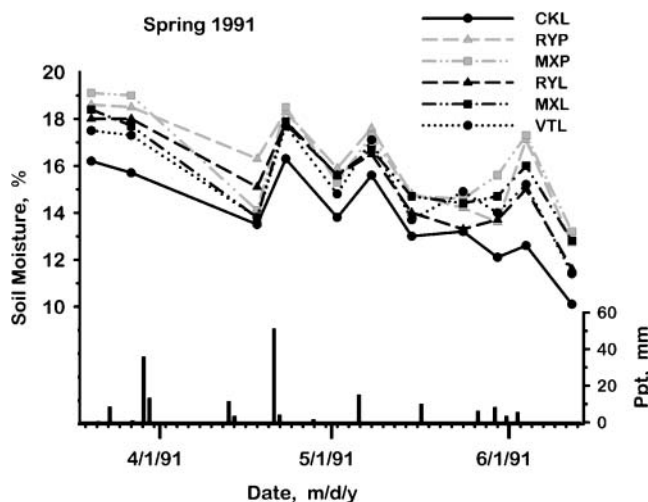


Fig. 3. Surface (0–20 cm) soil moisture contents (g water/100 g soil, i.e., %) during the spring of 1991 under cover crop and kill-date treatments of: rye killed early (RYP) or late (RYL), vetch killed late (VTL), vetch-rye mixture killed early (MXP) or late (MXL), or no-cover (CKL).

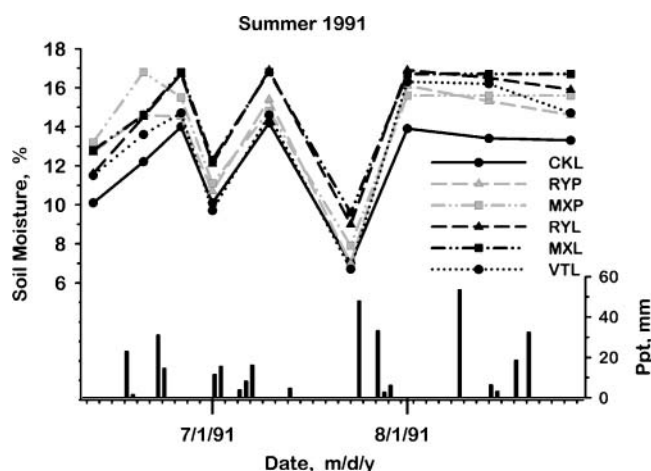


Fig. 4. Surface (0–20 cm) soil moisture contents (g water/100 g soil, i.e., %) during the summer of 1991 for high FN plots receiving cover crop and kill-date treatments of: rye killed early (RYP) or late (RYL), vetch killed late (VTL), vetch-rye mixture killed early (MXP) or late (MXL), or no cover (CKL).

did the no-cover check. In addition, cover crop residue conserved soil moisture for the corn during several dry periods encountered during the summer, as evidenced by visible signs of greater corn water stress on the no-cover plots. Similar results on water use and water conservation have been reported (Clark et al., 1995, 1997) for HV residue. Conversely, results from Virginia (Vaughan and Evanylo, 1998) concluded that cover crop N availability was more important for corn yield potential than soil moisture conservation. However, the Vaughan and Evanylo study was based entirely on yield from unfertilized corn where N availability, not water, was the dominant yield limitation. The soil moisture data of Table 2 and Fig. 4 were obtained under non-N limited conditions and illustrate the moisture conservation benefits of a cover crop mulch, which agrees well with earlier data from Virginia (Jones et al., 1969) and Georgia (Gallaher, 1977).

CONCLUSIONS

The vetch-rye mixture was intermediate to pure vetch and pure rye with respect to corn yield response to FN and the economic optimum FN rate. Managing vetch-rye mixtures with a GSH did not markedly change the corn FN response compared to conventional late-kill management. The average economic optimum FN rate was about 150 kg FN ha⁻¹ for the no-cover control, while HV replaced about 80 kg FN ha⁻¹ and the late-killed mixture replaced about 45 kg FN ha⁻¹. The early kill mixture required an extra 15 kg FN ha⁻¹ and the rye plots required an average of 50 kg as additional FN ha⁻¹, compared with the control.

The major effect of cover crops on surface-soil moisture was one of moisture conservation by cover crop residue during the spring and summer. Spring soil moisture depletion by cover crops did not occur under the relatively ample rainfall conditions of this study. In 2 yr with different spring and summer rainfall patterns, soil moisture was lower during the spring where no-cover

crop was grown and generally remained lower without a cover throughout the summer growing season.

The legume–grass cover crop mixture shows promise for alleviating many of the detrimental effects of pure rye, such as lower N availability, but mixtures supply less N to the next corn crop than pure vetch.

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